

1 TITLE OF THE INVENTION

2 BRIGHTNESS ADJUSTING APPARATUS FOR STEREOSCOPIC CAMERA

3

4 BACKGROUND OF THE INVENTION

5 1. Field of the invention

6 The present invention relates to an apparatus for
7 automatically adjusting a balance of brightness of a stereoscopic
8 camera.

9 2. Discussion of the background art

10 In recent years, a stereoscopic vehicle surrounding
11 monitoring apparatus using a pair of left and right cameras
12 (stereoscopic camera having solid image element like CCD) mounted
13 on the vehicle has been interested by automobile engineers. To
14 detect a distance to an object, first respective picture element
15 or pixel blocks having coincidence of brightness are found in
16 left and right images (hereinafter referred to as stereomatching),
17 then distance data are calculated according to the principle of
18 triangulation from a relative deviation amount between both pixel
19 blocks. Consequently, in order to calculate distance data with
20 high reliability, it is necessary to balance the brightness
21 between left and right cameras.

22 *ans. a)* With respect to this, Japanese Patent Applications
23 Laid-open No. Toku-Kai-Hei 5-114099 and No. Toku-Kai-Hei 5-
24 26554 disclose a technique in which variations of output image
25 signals which are caused by the difference of the output

1 characteristic of stereoscopic cameras and the like, are
2 corrected by referring to a lookup table. The lookup table is
3 for changing gains and offset amounts of image signals and is
4 stored in ROM of the system. Analogue image signals outputted
5 from each camera are adjusted by the lookup table after being
6 converted into digital signals by A/D converter. Thus,
7 variations of image signals are corrected and the accuracy of
8 the stereo matching is raised.

9 However, according to the aforesaid prior art, the
10 lookup table is established individually for a given stereoscopic
11 camera in the manufacturing process of the camera such that output
12 characteristics of the left and right cameras agree with each
13 other. The output characteristics of the stereoscopic camera,
14 however, gradually deviate from the initially set value due to
15 use environment or aged deterioration. Even if the output
16 characteristic is well-balanced at the initial stage, that
17 balance will be lost gradually, that is, the precision of the
18 stereo matching degrades due to aged deterioration.

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20 SUMMARY OF THE INVENTION

21 It is an object of the present invention to provide
22 an apparatus for automatically adjusting a brightness balance
23 of a stereoscopic camera to enhance the accuracy of monitoring
24 around the vehicle. To achieve the object, the brightness
25 adjusting apparatus comprises an adjusting means for adjusting

1 according to an embodiment of the present invention;

2 Fig. 2 is a flow chart showing processes for adjusting
3 gains according to a first embodiment of the present invention;

4 Fig. 3 is a flow chart continued from Fig. 2;

5 Fig. 4 is a diagram for explaining positions of a first
6 and second evaluation windows according to a first embodiment;

7 Fig. 5 is a diagram for explaining a searching range
8 of a second evaluation window;

9 Fig. 6 is a diagram for explaining an evaluation method
10 of a horizontal brightness edge (variation of brightness) in a
11 pixel block;

12 Fig. 7 is a flow chart showing processes for adjusting
13 gains according to a second embodiment of the present invention;
14 and

15 Fig. 8 is a diagram for explaining positions of a first
16 and second evaluation windows according to a second embodiment.

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18 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

19 Referring now to Fig. 1, a stereoscopic camera for
20 imaging the surrounding scenery of a vehicle comprises a pair
21 of CCD cameras 1, 2 disposed in the vicinity of a room mirror
22 in the compartment. The CCD cameras 1, 2 are transversely mounted
23 at a specified interval of distance. The camera 1 is referred
24 to as a main-camera for obtaining reference images and is mounted
25 on the right side when viewed from a driver. On the other hand,

1 Through these image processes, reference image data composed of
2 512 pixels horizontally and 200 pixels vertically are generated
3 from the output signals of the main camera 1. Further, comparison
4 image data are generated from the output signals of the sub camera
5 2. The comparison image data have the same vertical length as
6 the reference image data and a larger horizontal length than that
7 of the reference image data. For example, the comparison image
8 data are composed of 640 pixels horizontally and 200 pixels
9 vertically. These reference and comparison image data are stored
0 in an image data memory 7, respectively.

A stereo calculating circuit 6 calculates distance data based on the reference and comparison image data. Since one distance data is produced from one pixel block composed of 4×4 pixels, 128×50 distance data are calculated per one reference image of a frame size. With respect to a given pixel block in a reference image, a corresponding pixel block in a comparison image is identified by searching an area having the same brightness and the same pattern as that given pixel block of the reference image (stereo matching). The distance from the camera to an object projected in the stereo image is expressed as a parallax in the stereo image, namely a horizontal deviation amount between the reference and comparison images. Accordingly, the search is performed on the same horizontal line (epipolar line) as a j coordinate of the reference image. In the stereo calculating circuit 6, a correlation is evaluated between the object pixel

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1 block and the searching pixel block while shifting a pixel one
2 by one on the epipolar line. The correlation between the object
3 pixel block and the searching pixel block can be evaluated by
4 calculating a city block distance for example. Basically, a pixel
5 block whose city block distance is minimum is a pixel block having
6 the correlation. The parallax between the object pixel block and
7 the pixel block having the correlation is outputted as a distance
8 data. Since Japanese Patent Application Laid-open No. Toku-
9 Kai-Hei 5-114009 discloses a hardware constitution for
10 calculating the city block distance, detailed description is
11 omitted in this document. Thus calculated distance data of one
12 frame are stored in a distance data memory 8.

13 The micro-computer 9 (recognition section 10)
14 recognizes the road configuration (straight or curved road,
15 curvature of road etc.), solid objects ahead of the vehicle
16 (preceding vehicle, etc.) and the like. The recognition is
17 performed based on the image data stored in the image data memory
18 7 and the distance data stored in the distance data memory 8.
19 Further, other information not shown in the drawings such as
20 information from a vehicle speed sensor, a steering sensor, a
21 navigation system and the like, is referenced when it is necessary.
22 Specific approaches as to how to recognize the road configuration
23 and solid objects are disclosed in Unexamined Japanese Patent
24 Application No. Toku-Kai-Hei 5-265547. According to the result
25 of the recognition, when it is judged that an alarm is desired,

1 a warning device 11 such as a monitoring apparatus, a speaker
2 and the like operates to call a driver's attention. Further, by
3 controlling a control apparatus 12 as needed, a vehicle control
4 such as a shift-down of an automatic transmission, a slow-down
5 of engine power, or a depression of brake pedal, is carried out.

6 An operation according to a first embodiment will be
7 described. A calculation section 13 of the micro-computer 9
8 performs a feed-back adjustment of a gain of the gain control
9 amplifier 3a according to the flowcharts shown in Figs. 2 and
0 3. These flowcharts are carried out repeatedly in every cycle
1 of a specified time interval. The calculation section 13
2 calculates a main gain indicating value GMAIN for the main camera
3 1 and a sub gain indicating value GSUB for the sub camera 2, these
4 values are converted into analogue values by D/A converters 14,
5 14 respectively and the converted analogue signals are inputted
6 to the respective gain control amplifiers 3a, 3a.

17 First, at a step 1, a brightness data A1 of each pixel
18 existing in a first evaluation window W1 established in the
19 reference image is read. Fig. 4 is a diagram for explaining the
20 establishment of the first evaluation window W1 and a second
21 evaluation window W2 which will be described hereinafter. The
22 first evaluation window W1 is constituted by 16 x 16 pixels and
23 is fixed in a specified position ((a, b) in coordinates) in the
24 reference image expressed by i-j coordinates. Consequently, a
25 brightness data A1 having 256 pixels is read at this step. In

1 block is a value indicating a correlation object of this pixel
2 block (position of the correlation area in the comparison image).
3 That is, if the distance data is determined, the correlation
4 object of a given pixel block can be determined. Accordingly,
5 if the respective distance data in the first evaluation window
6 W1 have an adequate accuracy, the parallax x calculated according
7 to the foregoing method is a highly reliable value showing a
8 correlation object in the overall first evaluation W1.

On the other hand, it is possible to determine the position of the second evaluation window W2 without referring to the distance data d_i in the first evaluation window W1. In this case, the degree of correlation is evaluated overall area of 16×16 pixels while the evaluation is performed for every pixel one by one, starting from the basic point, coordinates (a, b) of the first evaluation window on the epipolar line ($j=b$) in the comparison image in the stereo matching direction (in this embodiment, rightwards). When an area having a largest correlation is found, this area is established to be a second evaluation window W2. However, this method has a defect that the calculation amount needed for searching the correlation object of the first evaluation window W1 substantially increases, compared to the foregoing method in which the distance data is used. The use of the distance data d_i existing in the first evaluation window W1 makes it possible to determine the correlation object of the first evaluation window W1 with less

1 amount of calculation.

2 The program goes from the step 2 to a step 3, in which
3 256 pieces of brightness data A2 existing in the second evaluation
4 window W2 are read. In order to evaluate the magnitude of overall
5 brightness of the evaluation windows W1, W2, a mean brightness
6 AVE1 of the first evaluation window W1 and a mean brightness AVE2
7 are calculated respectively (step 4). Here, the mean brightness
8 AVE1 (or AVE2) is a mean value of the 256 brightness data A1 (or
9 A2) read in the step 1 (or step 3). Further, thus calculated mean
10 brightness AVE1, AVE2 are stored in RAM of the micro-computer
11 9 (step 5).

12 When it is judged at a step 6 that 30 samples of the
13 mean brightness AVE1, AVE2 have been stored, the program goes
14 to steps after a step 7, in which gain indicating values GMAIN,
15 GSUB are subjected to adjusting processes. First, at the step
16 7 correlation coefficients R for evaluating the crrelationship
17 of the mean brightness AVE1, AVE2 of respective stored 30 samples
18 are calculated. When the respective samples are expressed in
19 (AVE1i, AVE2i i=1 to 30), the correlation coefficient R in the
20 entire samples can be calculated according to the following
21 formula.

22 [Formula 1]

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$$R = \frac{\sum (AVE1i - \overline{AVE1})(AVE2i - \overline{AVE2}) / 30}{\sqrt{\sum (AVE1i - \overline{AVE1})^2 / 30} \sqrt{\sum (AVE2i - \overline{AVE2})^2 / 30}} = \frac{\sum (AVE1i - \overline{AVE1})(AVE2i - \overline{AVE2})}{\sqrt{\sum (AVE1i - \overline{AVE1})^2} \sqrt{\sum (AVE2i - \overline{AVE2})^2}}$$

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1 brightness per each sample, SUM, a sum of the difference of the
2 mean brightness per sample is calculated according to the
3 following formula ($1 \leq i \leq 30$).

4 [Formula 2]

$$5 \quad \text{SUM} = \sum (\text{AVE1i} - \text{AVE2i})$$

6 The total amount of the difference of the mean
7 brightness SUM is theoretically 0, if the brightness balance
8 between the main camera 1 and the sub camera 2 is well-matched.
9 However, in consideration of the stability of control, in case
10 where the SUM is within a specified range (for example, -3500
11 to +3500), the present gain is judged to be in a proper condition.
12 In this case, both the main gain indicating value GMAIN and the
13 sub gain indicating value GSUB are not changed (steps 10, 13 and
14 15).

On the other hand, in case where the SUM is smaller than a negative threshold value (-3500), that is, in case where the comparison image outputted from the sub camera 2 is brighter than the reference image from the main camera 1, the program goes to a step 11 where 1 is added to the current sub gain indicating value GSUB and the main gain indicating value GMAIN is remained unchanged, that is, the current value GMAIN is used as it was. Since the added gain value makes the comparison image outputted from the sub camera 2 darker compared with the brightness before changing the gain, the unbalance of brightness between the cameras 1, 2 is adjusted in a reducing direction. Thus, the difference

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1 between the mean brightness AVE1 calculated in subsequent cycles
2 of the first evaluation window W1 and the mean brightness AVE2
3 of the second evaluation window W2 becomes small. Then, the
4 program goes to RETURN after at the step 12 the stored sample
5 data are cleared.

6 When the current sub gain indicating value GSUB is added
7 by 1, the sub gain indicating value GSUB sometimes goes beyond
8 an allowable correction range (for example, -30 to +30). In this
9 case, the sub gain indicating value GSUB is unchanged. That is,
10 instead of adding 1 to the sub gain indicating value GSUB, 1 is
11 subtracted from the current main gain indicating value GMAIN.
12 Since the reference image outputted from the main camera 1
13 increases the brightness compared to the one before the change
14 of gain, the brightness unbalance between the cameras 1, 2 is
15 adjusted so as to be extinguished. Further, in case where both
16 of the gain indicating values GMAIN, GSUB go beyond the allowable
17 correction range, it is judged that the adjustment is impossible
18 and neither values are not changed.

19 On the other hand, in case where the SUM is larger
20 than a positive threshold value (+3500), that is, in case where
21 the comparison image outputted from the sub camera 2 is darker
22 than that of the main camera 1, the program goes to a step 14
23 where I is reduced from the current sub gain indicating value
24 GSUB and the main gain indicating value GMAIN is used as it is
25 the current one. As a result, since the comparison image outputted

1 from the sub camera 2 becomes brighter than the one before changing
2 the gain, the brightness unbalance is adjusted so as to be
3 extinguished. Thus, the difference between the mean brightness
4 AVE1 of the window W1 and the mean brightness AVE2 of the window
5 W2 becomes smaller. Then, the program goes to RETURN after the
6 sample data stored is cleared at the step 12.

7 When the current sub gain indicating value GSUB is
8 reduced by 1, the sub gain indicating value GSUB sometimes goes
9 beyond an allowable correction range. In this case, the sub gain
10 indicating value GSUB is unchanged. That is, instead of reducing
11 1 from the sub gain indicating value GSUB, 1 is added to the current
12 main gain indicating value GMAIN. Since the reference image
13 outputted from the main camera 1 is darker than the one before
14 changing the gain, the brightness unbalance between the cameras
15 1, 2 is adjusted so as to be extinguished.

16 Thus, since the feedback adjustment of the gain is
17 performed in parallel with the monitoring control, the brightness
18 balance of the stereo camera can be automatically adjusted. As
19 a result of this, even if the initially set output characteristic
20 of the stereo camera changes due to the aged deterioration or
21 use environment, it is possible to adjust the balance of
22 brightness of the stereo camera properly. The distance data
23 calculated on the basis of thus obtained image signals can provide
24 more accurate monitoring around the vehicle.

25 Further, in this embodiment, the position of the second

1 evaluation window W2 which is the correlation object of the first
2 evaluation window W1 is established based on the distance data
3 existing in the first evaluation window W1. Since the second
4 evaluation window W2 is established in the position calculated
5 from this distance data, a deviation of the brightness balance
6 of the stereo camera can be detected accurately. As described
7 before, the distance data calculated with respect to a given small
8 region (pixel block) indicates a correlation object of the small
9 region. Accordingly, the most frequently appearing distance
10 value of the distance data existing in the first evaluation window
11 W1 which is an assembly of small regions, represents an overall
12 correlation object of the first evaluation window W1. Thus, it
13 is assured that both evaluation windows W1, W2 have approximately
14 the same brightness characteristics under the normal condition.
15 In other words, an existence of a deviation of brightness between
16 both evaluation windows W1, W2 means that there is a brightness
17 unbalance in the stereoscopic camera.

18 Further, the method of establishing the second
19 evaluation window W2 based on the distance data in the first
20 evaluation window W1 can reduce the quantity of calculation
21 substantially, compared to the method of finding the correlation
22 object of the first evaluation window W1 by searching an entire
23 comparison image. As a result, the micro-computer 9 does not need
24 so large a capacity. Further, this method has an advantage of
25 being able to adjust the brightness balance in real time in

1 parallel with the monitoring control around the vehicle.

2 Further, in this embodiment, the reliability of the
3 mean brightness AVE1, AVE2 (sample data) is verified based on
4 the correlation coefficient R. Only when it is judged that these
5 sample data are highly reliable, the gain adjustment is executed.
6 Accordingly, the gain adjustment can be performed properly
7 without being affected by noises and the like.

8 There are also the following variations of the
9 aforementioned embodiment.

10 (Variation 1)

11 According to the embodiment described above, the
12 parallax χ is obtained from the distance data d_i in the first
13 evaluation window W1 and then the position of the second
14 evaluation window W2 is established as coordinates $(a + \chi, b)$
15 based on the parallax χ . That is, the position of the second
16 evaluation window W2 is determined unconditionally from the
17 calculated parallax χ . On the other hand, according to a first
18 variation, a searching range of the second evaluation window W2
19 is established from the calculated parallax χ and an area having
20 a largest correlation in that range may be established as a second
21 evaluation window W2. Fig. 5 is a diagram for explaining the
22 searching range of the second evaluation window W2. Reference
23 coordinates F $(a + \chi, b)$ are determined based on the parallax
24 χ calculated from the distance data d_i of the first evaluation
25 window. The searching range is established to be a range having

1 among the distance data d_i of the first evaluation window W_1 .

2 Fig. 6 is a view for explaining a method of evaluating brightness

3 edges (variation of brightness) in the horizontal direction with

4 respect to a pixel block. First, a variation (absolute value)

5 of brightness ΔP_n ($n = 1$ to 16) of a pair of two horizontally

6 adjacent pixels is calculated. With respect to the far left pixel

7 line ($P_{11}, P_{12}, P_{13}, P_{14}$), a variation of brightness ΔP is calculated

8 from the far right line of a pixel block adjacent on the left.

9 Next, the number of brightness variations exceeding a specified

10 threshold value is counted from these 16 pieces of brightness

11 variations. If the number of brightness variations exceeding the

12 threshold value is equal to or smaller than 4, the pixel block

13 has no specific feature in brightness and its distance data is

14 judged to have a low reliability (invalid distance data). On the

15 other hand, if the number of brightness variations exceeding the

16 threshold value is larger than 4, the distance data of the pixel

17 block is judged to be highly reliable (valid distance data). The

18 parallax χ is calculated based upon only the valid distance data

19 among the distance data d_i in the first evaluation window W_1 .

20 The use of thus calculated parallax χ provides an establishment

21 of the second evaluation window W_2 in a more appropriate position.

22 Accordingly, it is possible to calculate the sample data AVE1,

23 AVE2 having a higher accuracy.

24 (Variation 3)

25 In the first embodiment, the first evaluation window

1 W1 is fixed in a specified position. On the other hand, according
2 to the variation 3, the position of the first evaluation window
3 W1 may be varied. For example, an area having the largest number
4 of the aforesaid valid distance data may be established to be
5 a first evaluation window W1. According to this method, since
6 an area including the most reliable valid distance data is
7 selected as a first evaluation window W1, its correlation object
8 can be precisely established.

9 Fig. 7 is a flowchart showing a process for adjusting
10 a gain according to a second embodiment of the present invention.

11 In the flowchart, first at a step 21, brightness data
12 A1 of sub zones R1, R2, R3 (hereinafter, referred to as first
13 zones) constituting the first evaluation window W1 in the
14 reference image are read. Further, at a step 22, brightness data
15 A2 of sub zones R4, R5, R6 (hereinafter, referred to as second
16 zones) constituting the second evaluation window W2 in the
17 comparison image are read.

18 Fig. 8 is a diagram for explaining the establishment
19 position of the first evaluation window W1 and the second
20 evaluation window W2. The first zones R1, R2 and R3 positionally
21 correspond to the second zones R4, R5 and R6, respectively. The
22 positions of R4, R5 and R6 of the second zones are established,
23 in consideration of the stereo matching, being offset slightly
24 from the positions R1, R2 and R3 of the first zones in the direction
25 of the stereo matching. The offset amount is established taking

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1 a general tendency with respect to the distance to objects which
2 would be generally projected in the first zones R1, R2 and R3
3 into consideration.

4 When a vehicle monitors ahead of the vehicle during
5 traveling, there is a tendency for the sky (infinite point) or
6 solid objects in the relatively far distance (for example,
7 buildings etc.) to be projected in the first zone R1 established
8 on a relatively upper side of the reference image and in the second
9 zone R4 corresponding to the first zone R1 in the comparison image.

10 Accordingly, since parallaxes calculated in these zones R1, R4
11 tend to become relatively small, considering the tendency of the
12 distance of solid objects and the like projected on the upper
13 part of the image, the offset amount with respect to the second
14 zones R4 is established to be smaller (or 0) beforehand. For
15 example, as shown in Fig. 8, the second zone R4 is offset from
16 the first zone R1 by the amount of 15 pixels in the stereo matching.

17 Further, since generally, there is a tendency for
18 vehicles traveling ahead of the self vehicle and the like to be
19 projected on the first zone R2 established in the middle part
20 of the reference image and the second zone R5 positionally
21 corresponding to the first zone R2, the parallax in the area tends
22 to become medium. Consequently, taking the tendency of the scenery
23 like this projected in the middle part of the image into
24 consideration, the offset amount of the second zone R5 is
25 established to be medium beforehand. According to the result of

1 evaluation window W1 and the mean brightness AVE2 of the second
2 evaluation window W2 are calculated respectively. To reduce the
3 calculation quantity, the mean brightness AVE1 is calculated
4 from the brightness data A1 of every two horizontal lines in the
5 first zone R1, R2 and R3. Further, similarly the mean brightness
6 AVE2 is calculated from the brightness data A2 of every two
7 horizontal lines in the second zones R4, R5 and R6. The mean
8 brightness AVE1, AVE2 calculated in a certain cycle are stored
9 in the RAM of the micro-computer 9 (step 24).

10 The processes from the step 21 to the step 24 are
11 repeated in each cycle until 30 samples of the mean brightness
12 data AVE1, AVE2 are stored. When the 30 samples of the mean
13 brightness data AVE1, AVE2 are stored, the program goes from the
14 step 25 of the cycle to the step 7 in the flowchart of Fig. 3.
15 The processes after the step 7 are the same as those in the first
16 embodiment and the description here is omitted.

17 Also in this embodiment, similarly to the first
18 embodiment, since the brightness balance of the stereoscopic
19 camera can be automatically adjusted so as to be in a proper
20 condition, the accuracy of the surroundings monitoring can be
21 enhanced.

22 Further, according to the second embodiment,
23 differently from the first embodiment, the second evaluation
24 window W2 is established without referring to the distance data.

1 Accordingly, the brightness balance can be effectively adjusted
2 under the condition that the stereoscopic camera has a relatively
3 large brightness deviation or positional deviation, that is,
4 under the condition that this makes it impossible to calculate
5 the highly reliable distance data. Such condition happens for
6 example in a stage of the initial setting of at shipping of a
7 stereoscopic camera or in an event of a readjustment thereof due
8 to dead battery-backup or the like.

9 While the presently preferred embodiments of the
10 present invention have been shown and described, it is to be
11 understood that these disclosures are for the purpose of
12 illustration and that various changes and modifications may be
13 made without departing from the scope of the invention as set
14 forth in the appended claims.